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On-Demand Controls for Central Hot Water Systems White Paper

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Introduction and Scope

This report aggregates and summarizes the state of the art for on-demand controls applied to central hot water systems in multi-family buildings. Multiple field demonstrations have been executed in California, Illinois, and Michigan, among other states, and select utilities have prepared work papers on this technology for use in their Energy Efficiency Programs (EEP). Publically available field studies that include savings data across multiple installations, ranging from a few to dozens, have been developed in recent years. Available data has reached a tipping point, but without a mechanism for consolidating these resources, it has been difficult and tedious for interested utilities to access and evaluate information about this technology and the value it may bring to their own EEP.

This white paper is divided into two general sections: a foundational utility work paper and detailed supporting analyses and discussions. The foundational utility work paper is designed to be a general starting draft for utilities that are considering incorporating this technology into their EEP. The foundational utility work paper can be exported from the white paper and modified as appropriate for a utility's individual program circumstances and regulatory requirements. The balance of this white paper focuses on the supporting analyses and information about this technology and can be a valuable resource for utilities to further refine their approach to incorporating this technology within their own EEP.

This white paper reflects the best information available at the time of its writing. It is presumed that there are additional confidential data and reports that exist, but were not accessible to the white paper authors. As such, the scope of this white paper should be understood to reflect a detailed snapshot in time of information available in the public record and through select work funded by GTI North American ETP Participants.

Foundational Utility Work Paper

Measure Summary

On a per Demand Controlled Pump Basis

Building Type	Building Vintage	Peak Electric Demand Reduction (kW/ pump)	Electric Savings (kWh/ pump)	Gas Savings (therms/ pump)	Base Case Cost (\$/pump)	Measure Cost (\$/pump)	Measure Incremental Cost (\$/pump)	Effective Useful Life (years)
Multi-family	All	0 (negligible)	1,230	1,484	\$900	\$2,100	\$1,200	15 years

*Although some multi-family buildings have electric central water heating, they are much less common and are therefore not included as an alternate measure or base case.

On a per Dwelling Unit Basis

Building Type	Building Vintage	Peak Electric Demand Reduction (kW/ pump)	Electric Savings (kWh/ pump)	Gas Savings (therms/ pump)	Base Case Cost (\$/pump)	Measure Cost (\$/pump)	Measure Incremental Cost (\$/pump)	Effective Useful Life (years)
Multi-family	All	0 (negligible)	1,230	See formula in Gas Energy Savings Estimation Methodology	\$900	\$2,100	\$1,200	15 years

Measure Description	On-demand controls and pump for a multi-family gas-fired central water heating system. The on-demand controls turn off the recirculation loop when it is not needed, thereby reducing unnecessary heat loss from the loop, reducing the boiler fire time, and thus reducing the natural gas consumption and electricity that runs the pump.
Energy Impact Common Units	Per pump OR per dwelling unit
Base Case Description	24/7 uncontrolled recirculating hot water pump. This includes pumps that have controls that have been bypassed.
Base Case Energy Consumption	Varies by building
Measure Energy Consumption	Measure therm and kWh energy consumption varies by building
Costs Common Units	Per pump
Base Case Equipment Cost (\$/unit)	\$400
Base Case Labor/Installation Cost (\$/unit)	\$500
Base Case Maintenance Cost (\$/unit)	\$0
Measure Equipment Cost (\$/unit)	\$1,600
Measure Labor/Installation Cost (\$/unit)	\$500
Measure Maintenance Cost (\$/unit)	\$0
Measure Incremental Cost (\$/unit)	\$1,200
Effective Useful Life (years)	15 years ^{1,2,4}
Program Type	Retrofit before the end of existing equipment's useful life
Net-to-Gross Ratio	0.7 to 1.0 ^{11,12,13}

General Measure and Base Case Data

Measure Description and Background

This measure addresses the installation of demand controls on Central Domestic Hot Water (CDHW) systems with a recirculation loop in multi-family residential end-use applications, while improving occupant satisfaction with the hot water delivery. The installation of demand controls on CDHW systems with recirculation loops is intended to capture energy savings from heating domestic water supply. Technologies utilized to lower the energy loss in recirculation loops include demand controls, time clocks and aquastats. While each has some advantages and disadvantages, none except demand controls can respond in real time to hot water demand, which is critical to preserve function, minimize complaints, and maximize energy savings.

In a CDHW system with no controls (base case), the pump continuously circulates hot water through the recirculation loop 24 hours a day, 7 days a week, even during periods with no hot water use. In this scenario, the recirculation loop is continuously losing heat to the surrounding environment. Eventually, this heat loss will require the boiler to fire to maintain the water temperature. A demand control system activates the pump only when there is hot water demand and the hot water return temperature is below a setpoint temperature, thereby eliminating unnecessary boiler firing.

This measure requires that there be no existing controls or any existing controls, such as a time clock or aquastat, must be verified to be non-operational. This equipment is considered a new measure type as defined by the utility.

The target customers for this measure are associated with the residential housing industry, such as owners and operators of multifamily dwellings. The intent of offering this measure is to help these customers reduce energy usage through a streamlined, cost-effective delivery. Multifamily dwelling owners and operators and the vendors that serve them are able to access rebates for this energy efficiency measure without the complication and delay associated with a custom incentive process.

Demand Control Measure Requirements

- The end user must have natural gas and/or electricity distributed by this utility company to the installation address.
- There must be an existing CDHW system with a recirculation loop in place.
- There must be no controls OR the controls must be verified to be non-operational.
- Product specifications and cut sheets must be provided in order to document that the product meets the following measure requirements:
 - o demand controls must be able to activate the operation of hot water recirculation based on changes in real-time hot water demand, and
 - o demand controls must be able to terminate the operation of hot water recirculation based on a setpoint temperature for the recirculation return line.

Technical Description

Demand controlled pumps (measure case) use a water flow sensor and an adjustable temperature sensor to monitor real-time events. In order for the pump to come on, there must be a demand for hot water and the temperature of the return line must be lower than a certain temperature setpoint. When hot water is needed the pump is activated and it moves water through the

recirculation loop until the hot water has completed one full circuit and returned back to the boiler room, which indicates availability of hot water throughout the building. When there is no demand, the hot water stays in the insulated storage tank, which is much more efficient at retaining heat than the hot water pipes. In order to maximize energy efficiency, today's technologies must react in real-time and in a manner that continues to provide a high level of service, otherwise the technology runs the risk of being disabled shortly after installation.

Demand controls on hot water recirculation systems turn off the recirculating pump when it is not needed, thereby reducing unnecessary heat loss from the recirculation loop, reducing the boiler fire time, and thus reducing the natural gas consumption. Recent California Energy Commission research indicates that heat losses from the recirculation loop can account for an average of 33% of the CDHW natural gas energy consumed, with a range from 9% to 63%.^{3,4} Data also shows that a substantial number of multi-family boilers either have no recirculation controls installed (base case), or if they do have a control, it is often a time clock, which is almost always bypassed.¹ This measure offers an alternative that is appropriate, sustainable and saves natural gas and electricity while maintaining comfort for the occupants.

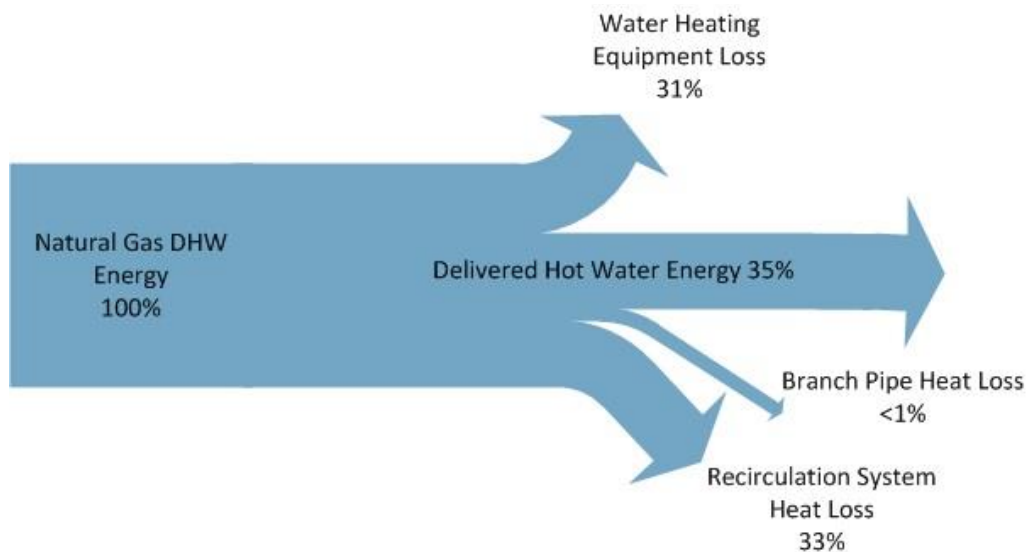


Figure 1. Average Energy Flows in Multi-Family Central DHW Systems

Source: Zhang, Yanda. Heschong Mahone Group. 2013. Multifamily Central Domestic Hot Water Distribution Systems. California Energy Commission. Publication Number: CEC-500-2013-011.

Code Analysis

State/Local Codes

State or local codes may be applicable to this technology. Determinations will need to be made by individual utility companies. At the time of this report writing, the only state with language relating to on-demand controls is Oregon. There is also model language developed by the International Code Council (ICC) in a green construction standard called the International Green Construction Code (IgCC). Some states have adopted the IgCC. The ICC maintains a document titled “International Codes- Adoption by State”, which is a starting resource for conducting a

code analysis.⁵ Additionally, California made demand controls the baseline prescriptive requirement through Title 24 Building Standards starting January 1, 2014.⁶

Federal Standards

This measure does not fall under Federal DOE or EPA Energy Regulations. The 2013 edition of the DOE Standard Work Specification Guidelines for Multifamily Buildings Weatherization Assistance Program (WAP) does provide guidelines for demand controls to support and promote high quality work.⁷ These Guidelines are a resource that can be used by contractors, trainers, homeowners, or utility energy efficiency program administrators working on whole-building energy upgrades, but is primarily aimed at work executed by WAP technicians.

Market Potential and Other Studies

In 2013, the Nicor Gas Emerging Technology Program (Nicor Gas ETP) completed pilot deployments of this measure in two multi-family buildings in the greater Chicago area: a 23-unit, three-story building and a 51-unit, three-story building. The Nicor Gas ETP alternated between continuous operation and on-demand operation on a weekly basis for approximately four months to determine the measured energy savings. The Nicor Gas ETP found savings of 19.9% and 22.8% at the sites, with an average of 54 therms saved per apartment.⁸ A subsequent review of the energy savings by Navigant showed a 100% realization rate of the *Ex Ante* gross savings calculated by the Nicor Gas ETP.⁹ Since the Nicor Gas ETP was an emerging technology program rather than a traditional energy efficiency program (EEP), key variables such as the appropriate net-to-gross ratio were defined for use by other ETPs rather than by a conventional, prescriptive EEP.

There have been many other studies focusing on this measure, including field monitoring by the Hescong Mahone Group, Inc. (HMG) for a Public Interest Energy Research (PIER) project conducted from 2008 to 2010.³ HMG completed detailed monitoring of DHW systems in 28 buildings of varying sizes and DHW/recirculation loop configurations, covering five California climate zones. HMG collected granular data for eight of these buildings for more than one year with various recirculation loop control strategies, including timer, temperature modulation, and demand controls. HMG found measure energy savings from the demand controls ranging from a 0% savings minimum and a 32% savings maximum, with a median savings of 11%, while noting that variations in DHW system operation conditions, particularly hot water usage levels, appeared to be the driver for uncertainties in the energy savings analysis.³

In September 2009, the Benningfield Group completed field monitoring of a sample of PY2008 and PY2009 installations of this measure under the Southern California Gas On-Demand Efficiency (ODE) Program. The field monitoring covered a total of 35 sites, alternating on a weekly basis between on-demand mode and continuous operation mode of the recirculation loop. Benningfield Group found that their monitored results indicated 1,526 therms were saved per measure installation, which equaled 96% of their expected *ex ante* savings estimate.¹ On a per dwelling unit basis, the savings ranged from 17.8 therms/apt to 95.7 therms/apt, with an average of 35 therms/apt for this measure.¹

This measure reduces heat losses from the recirculation loop, which means that the energy savings is expected to be similar for residential and commercial buildings, provided they have a central recirculation loop. Field testing has largely focused on multi-family buildings to date, though some monitoring has been completed for commercial end uses. Southern California Gas completed a year-long monitoring study of the measure at a 12-unit timeshare hospitality site in

California in 2010. The measure showed an annual gas savings of 11.7%, with higher savings in the fall and winter and lower savings in the spring and summer.¹⁰

Each of these studies is included in the Key Resources and References for Additional Information section and can be reviewed for additional details.

Measure Effective Useful Life

The measure effective useful life is 15 years, in accordance with the lifetime cited in numerous past field testing reports, utility work papers, and energy efficiency databases, such as California's Database of Energy Efficiency Resources (DEER) 2011 database.^{1,2,4}

Net-to-Gross Ratios

The net-to-gross (NTG) ratio for this measure may vary based on measure classification, program assignment, program delivery approach, or utility/state given applicable regulatory guidance. The following ratios are samples of applicable NTG ratios that may apply to this measure.

The California 2011 Database for Energy Efficiency Resources (DEER) identifies a default NTG ratio of 0.70 for any new technology energy efficiency measure without an evaluated NTG that has been in a program for two years or less.¹¹

NTG ratios for multi-family gas programs in Illinois are 0.90 (Nicor Gas) and 0.67-0.94 (Peoples Gas and North Shore Gas).¹²

The Massachusetts Technical Reference Manual does not include a NTG for this measure, but shows 1.0 for boiler reset controls as a residential gas measure, which may be considered a reasonable proxy.¹³ Massachusetts also notes that all NTG ratios are set to 1.0 when there are no completed evaluations available.

Energy Savings and Demand Reduction Calculations

The energy savings calculations for this measure case are based on detailed field testing and monitoring that has been completed in over 40 multifamily buildings in California, Illinois, and Michigan. The base case is 24/7 recirculation pump operation, while the measure case is demand controls on a CDHW system. The average gas savings across the cited field studies is about 14%. The average electric savings is just over 90%, primarily since the pump runtime is substantially reduced by the demand controls. Details regarding the monitoring approach, timeframes, and results can be found in the original reports cited in the Key Resources and References for Additional Information section.

Load Shapes for Measure and Base Case

The kW demand reduction is negligible for this measure. In fact, the measure case as a pump wattage that is 6 W higher than the base case (though individual pump wattage will vary from site to site); however, since the run time is much shorter for the measure case, this does not result in an overall increase in electric use.

Electric Energy Savings Estimation Methodology

Results from 2009 field monitoring by the Benningfield Group, 2013 field monitoring by DTE Energy, and 2013 field monitoring by the Nicor Gas Emerging Technology Program indicate that the pump runtime was reduced significantly with the implementation of the measure case. Past field datasets generally reported total kWh usage reduction across the building, rather than

normalizing per dwelling unit. As such, this was deemed the most appropriate method for this work paper. On average, the daily pump runtime was reduced by nearly 92%, resulting in an average measure case pump runtime of 1.9 hours per day. The average base case pump wattage shown in these two field monitoring efforts was 153 Watts/pump, while the measure case pump is assumed to be 159 Watts/pump.

The annual electric energy savings is 1,230 kWh per pump, which is a 95% reduction from the base case.

Δ Watts/unit:

The demand difference (watts per pump) is simply the difference between the electric demand of the base case unit and the electric demand of the energy efficient measure unit.

$$\begin{aligned}\Delta\text{Watts/pump} &= \text{Base Watts/pump} - \text{Measure Watts/pump} \\ &= 100 \text{ Watts} - 90 \text{ watts} = 10 \text{ watts}\end{aligned}$$

Annual Electric Savings:

$$\begin{aligned}\text{Energy Savings [kWh/pump]} &= \frac{(\Delta\text{Watts/pump}) \times (\text{hours/day}) \times (\text{days/year})}{1,000 \text{ Watts/kW}} = \\ &= [[(153 \text{ W} \times 24 \text{ hours/day}) - (159 \text{ W} \times 1.9 \text{ hours/day})] \times 365 \text{ days/year}] / 1,000 \text{ W/kW} \\ &= (3672 - 302) \times 0.365 \\ &= 1,230 \text{ kWh/year/pump}\end{aligned}$$

Demand Reduction Estimation Methodology

The anticipated demand reduction associated with this measure is negligible. In fact, the measure case as a pump wattage that is 6 W higher than the base case; however, since the run time is much shorter for the measure case, this does not result in an overall increase in electric use.

Gas Energy Savings Estimation Methodology

There are two approaches that may be used for determining the natural gas savings of this technology: on a per pump or per dwelling unit basis. Both of the options are outlined below and the most appropriate may be selected depending on the structure of the utility rebate and regulatory environment.

Per Demand Controlled Pump Basis

Results from 2009 field monitoring by the Benningfield Group, 2013 field monitoring by DTE Energy, and 2013 field monitoring by the Nicor Gas Emerging Technology Program indicate that the average overall gas savings per pump was 1,484 therms/year.

$$\begin{aligned}\text{Annual Gas Savings: Annual Base Case Usage} - \text{Annual Measure Case Usage} \\ &= 1,484 \text{ therms/year/pump}\end{aligned}$$

Per Dwelling Unit Basis

Results from 2009 field monitoring by the Benningfield Group, 2013 field monitoring by DTE Energy, and 2013 field monitoring by the Nicor Gas Emerging Technology Program were aggregated into a single dataset, with total savings broken down by average therms per number

of dwelling units. The resulting X-Y scatter plot was fitted with an exponential regression line yielding the following formula:

$$Y = 50.049e^{-0.009x}$$

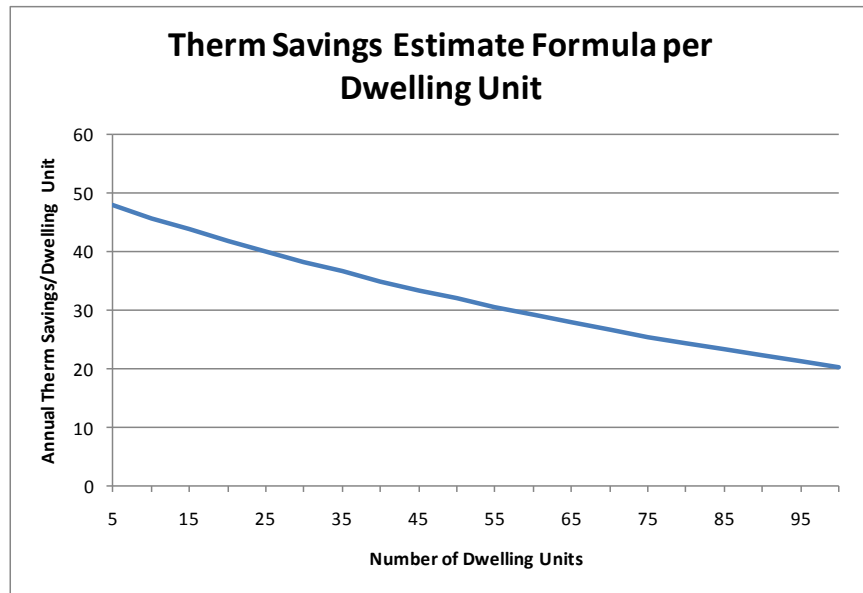


Figure 2. Therm Savings Estimate Formula per Dwelling Unit

The number of dwelling units at an installation site could be entered as the “x” variable and the average therm savings per dwelling unit could then be calculated as the “y” variable. This approach would enable some adjustment to be made based on the total size of the building rather than relying on a fixed gas savings value per pump.

Measure and Base Case Costs

Table 1. Base Case Equipment and Labor Costs

Measure Application Type	Baseline	Equipment Cost ¹	Labor / Installation Cost ¹	Maintenance / Other Cost	Total Measure Cost
New Construction, Time of Sale	Recirculation Pump without Controls*	\$400 / pump	\$500 / pump	\$0	\$900 / pump
Retrofit	Recirculation Pump without Controls*	\$0	\$0	\$0	\$0

**Or with verified disabled or bypassed controls*

Table 2. Measure Case Equipment and Labor Costs

Measure Application Type	Baseline	Equipment Cost ¹	Labor / Installation Cost ¹	Maintenance / Other Cost	Total Measure Cost
New Construction, Time of Sale, or Retrofit	Recirculation Pump without Controls*	\$1,600 / pump	\$500 / pump	\$0	\$2,100 / pump

Table 3. Incremental Cost

Measure Application Type	Incremental Measure Cost
New Construction, Time of Sale	\$1,200 / pump
Retrofit	\$2,100 / pump

Status of Technology in North American Energy Efficiency Program

Demand controls are currently being deployed in a limited number of utility efficiency programs throughout the U.S. The following table shows existing programs where consumers have received rebates and incentives by implementing demand controls in their buildings' hot water system.

Table 4. Demand Control Incentives in North American Efficiency Programs

Energy Efficiency Program	Program Administrator	Eligible Buildings	Type of Program	Incentive / Rebate
Southern California Gas On-Demand Efficiency Program	Benningfield Group	Multi-family with 6+ dwelling units and CDHW	Direct install	Covers total cost of installed measure
SDG&E Energy Efficiency Business Incentives	SDG&E	Commercial rate buildings within SDG&E service territory	Custom incentive	\$1.00/therm and \$0.10/kWh based on calculated annual savings, up to 50% of project cost
Palo Alto Utilities Hospitality/ Multi-Family Program	Synergy Companies	Hotels, motels, multi-family	Prescriptive rebate	\$1,500 per demand controller
Energy Trust of Oregon Multi-Family Efficiency Program	Lockheed Martin	Multi-family with a minimum of 3 stories and CDHW	Prescriptive rebate	\$420 per demand controller
NV Energy Sure Bet Program	KEMA	Commercial rate buildings	Custom incentive	\$0.50/therm up to 50% of project cost
Puget Sound Energy Multi-Family Retrofit	Ecova	Multi-family programs	Custom incentive	Based on PSE analysis

Energy Efficiency Program	Program Administrator	Eligible Buildings	Type of Program	Incentive / Rebate
National Grid	RISE Engineering	Multi-family buildings	Custom incentive	Calculated basis
Connecticut Natural Gas	CNG	Commercial and multi-family buildings	Custom incentive	Lesser of 40% of project cost of the Utility Measure Caps
Efficiency Vermont	Vermont Energy Investment Corp.	Commercial buildings	Custom incentive	Determined on a case-by-case basis
Nicor Gas Multi-family Comprehensive Energy Efficiency Program	Franklin Energy	Multi-family buildings with at least 20 dwelling units and no more than 50.	Prescriptive rebate	\$30 per dwelling unit

These programs are responsible for the vast majority of retrofit activity in multi-family and commercial CDHW systems in the U.S. Program participation is driven in large part by the level of rebate or incentive that is provided by the program, as well as the level of marketing and outreach. Programs that utilize a direct install approach or that have incentives that cover much or all of the installed measure cost have the highest participation levels, and therefore are capturing the highest level of savings.

To illustrate, one of the best known examples of program effectiveness for this measure is the “On-Demand Efficiency” program, a 3rd party direct install program that is funded by Southern California Gas Company and administered by Benningfield Group. Over 1,200 demand controllers were installed in 2013 and participation has been growing steadily every year since its inception in 2008. As a result, Southern California Gas has also increased the level of funding to meet the increasing demand for the program through 2014.

Comparison of Prescriptive Savings and Costs

Given the number of previous research studies, this white paper intended to review the datasets from a range of recent reports and address key research questions regarding field monitoring results. Two outstanding questions identified in the research body are:

1. How do energy savings from the measure differ in cold and warm climates?
2. What building characteristics are the best predictors of energy savings?

The authors reviewed eight past research efforts to identify information on these two topics and consolidate and interpret findings as presented in the following sections.

Energy Savings across Cold and Warm Climates

The energy savings associated with on-demand controls for CDHW recirculation loops is driven by a reduction in heat losses through the DHW distribution piping when hot water is moving unnecessarily throughout the building. This reduction in heat losses leads to a reduced number of boiler firings, which saves further energy. With these two variables driving much of the energy savings, it can be estimated that in colder climates where ambient building temperatures are likely to be lower on average during the winter months, this measure may result in larger energy savings than in warmer climates where the rate of heat loss from the distribution piping is slower.

Previous field research has generally been focused in a single utility territory, which limits the ability to capture a range of climates. The largest publically available studies have been in California. Although California has a number of separately defined micro-climate zones, the majority of the state is within ASHRAE climate zone 3. Thus the results are still representative of a limited and relatively warmer climate on a nationwide scale.

Under the scope of this white paper, a variety of publically available studies were reviewed and where possible datasets were consolidated to allow for comparison. Unfortunately, the consolidated dataset included 36 field sites in warm climates with sufficient data and only 8 sites with sufficient data in cold climates. This dataset is considered to be too small to allow for a reasonable comparison of results, particularly given other factors that can affect energy savings levels, such as CDHW distribution system design, piping insulation, occupancy levels, and hot water usage patterns.

Normalized Energy Savings by Various Metrics

In a 2009 report, the Benningfield Group monitored 35 sites in Southern California and compared different independent variables for normalizing the energy savings, including number of dwelling unit served by the demand controls (R-squared = 0.59), total hot water storage capacity (R-squared = 0.97), and the number of stories (R-squared = 0.81).¹ They found the strongest correlation (R-squared) when comparing therm savings to the total hot water storage capacity.¹ The likely reason behind this strong correlation is the base case pump is continuously mixing the temperature in the storage tank with cooler water from the return line of the recirculation loop, constantly cooling the storage tank and causing the boiler to fire. However, the measure case demand controls allow the larger tank to stratify during periods of little or no use, while still providing enough hot water from the top of the tank to meet modest needs without activating the pump.

The Benningfield Group analysis suggested total hot water storage capacity may be a more appropriate variable for predicting energy savings and thus potentially a good basis for rebating the technology. However, no currently available utility rebates have been structured based on the total hot water storage capacity, including those in California. Utility rebates have been offered either at a fixed level per demand controller, based on the number of dwelling units served by the measure, or at a customized incentive level based on savings. The On-Demand Efficiency program in Southern California Gas territory did briefly implement rebates based on hot water storage capacity, with different rebate levels for systems smaller than 250 gallons and greater than 250 gallons. However, since the vast majority of applicants had hot water storage capacities of less than 250 gallons, the rebate structure was deemed to not be of sufficient value and

abandoned under recommendation by the California Public Utilities Commission to be consistent with other utility work papers.

In a February 28, 2013 work paper disposition by the California Public Utilities Commission Energy Division staff recommended that “savings values shall be based on the number of dwelling units rather than on a whole building”.¹⁴ Part of the reasoning for this may be that most multi-family prescriptive rebates - such for low-flow showerheads, faucet aerators, or thermostats - are typically incentivized on a per dwelling unit basis or at a fixed level. Structuring the on-demand controls rebate in such a similar way would maintain program consistency.

Program Implementation Approaches

Of the 10 energy efficiency programs that currently offer incentives for CDHW demand controls highlighted in Table 4, three are offered as prescriptive rebates, six are offered as custom incentives, and one is offered as a direct installation option. Each of these approaches offers its own benefits and limitations. A prescriptive rebate can often be deployed more widely since the customers are guaranteed a specific financial value up-front. From a programmatic perspective, prescriptive rebates can also offer the benefit of being a more stream-lined implementation option than requiring custom calculations and application processing for each installed measure. However, prescriptive rebates generally require some up-front time investment by the utility or third party program implementer to draft a work paper, including a savings algorithm and delivery method, as well as develop Technical Reference Manual inputs, if required by regulators.

A custom incentive generally requires more application processing and time investment on behalf of the program implementer, but yields a more individualized savings estimate. From the customer’s perspective, it can mean a longer wait time and more paperwork to receive the incentive, but also may increase their total incentive level if the measure shows strong energy savings. Custom incentives can be more cost-effective for utilities or third party implementers if they expect a relatively limited number of the measures to be installed annually within their territory, or if they expect the energy savings to vary significantly on a case-by-case basis.

Southern California Gas On-Demand Efficiency program is designed specifically for the delivery of this measure (and no others), so their direct install approach is a cost-effective way to encourage easy adoption by customers and still maintain detailed information to determine and evaluate the program’s performance. The direct install program relies on a network of contractor partners to consistently deliver the measure to customers and who understand and can navigate the program requirements. The rebate is provided directly to the contractor and, in the case of the On-Demand Efficiency program, offsets 100% of the customer’s cost. In addition to this approach being extremely easy for the customer – no paperwork, no upfront cost – it also can gain additional outreach and marketing support by having these contractors as “boots on the ground” to drive increased market adoption.

Next Steps for Technology – New Markets, New Opportunities

To date, on-demand CDHW controls have been primarily installed in multi-family buildings, the majority of which have been in Southern California Gas territory where there have been incentives available. There is great potential for the utilization of this technology in other

geographic areas, as well as in other types of buildings. The CDHW systems in multi-family buildings are designed and constructed in a similar way to commercial and other multi-unit buildings. Thus similar energy savings should be achievable. The following building types would be expected to have comparable savings to a multi-family building:

- Hotels, Motels, Resorts, Timeshares, and other lodging and hospitality structures¹⁵
- School Dormitories (Secondary Schools, Colleges, Universities, etc.)
- Military Housing, Barracks

The common thread in the above structures is they are generally buildings where people reside and where domestic hot water usage is higher due primarily to showers. There have been a handful of the above structures that have been studied, but for the most part these markets are completely untapped in regards to on-demand CDHW controls. Figure 3 shows the estimated average payback period, implementation year, and market size for each of these building types. The average payback period and implementation year may vary depending on the availability of financial incentives that may spur market development.

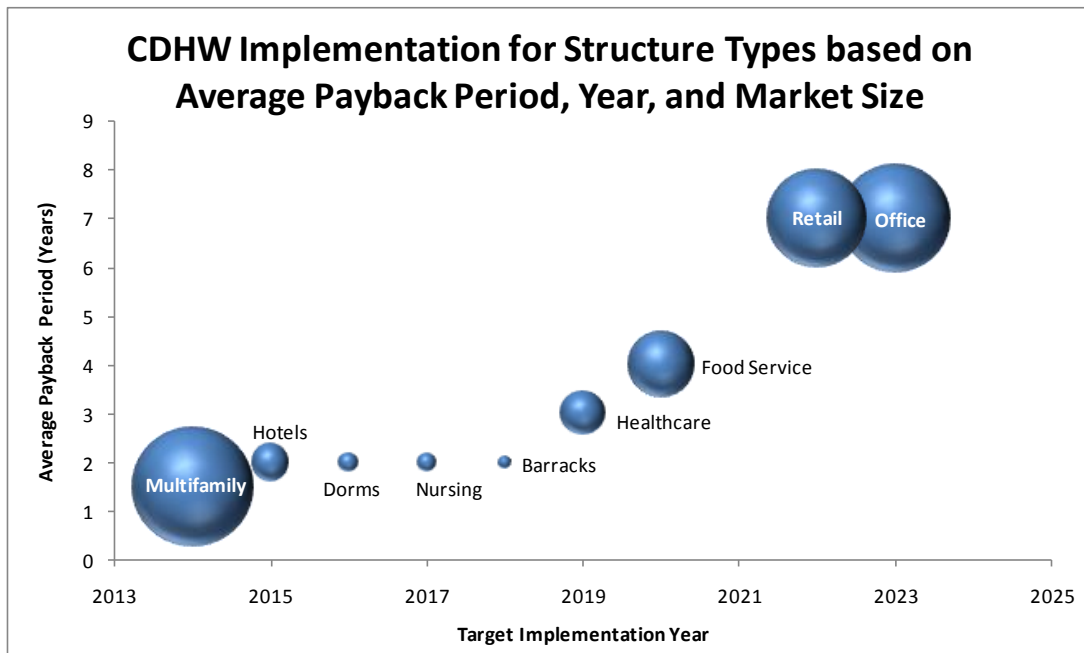


Figure 3. Market Potential by Building Type and Implementation Year

There is also some potential for energy savings in other commercial buildings such as office, food service, retail, and healthcare facilities. The method of turning off circulation of hot water when it is not needed would be just as or more effective as in a multi-family building due to longer periods where the hot water is not being used, but since the domestic hot water load is much smaller in these building categories, the absolute savings would not be as great, thus extending the payback.

When the technology becomes further commercialized and is a mainstream product in the plumbing industry, the price point of the technology would be expected to come down, opening up the possibility of cost-effective savings in the offices, food service, retail, and healthcare facilities. It should be noted that some of these facilities, such as healthcare, may have unique codes and standards requirements that would need to be addressed prior to wide adoption of the technology.

From a technological standpoint, the on-demand controls use sensors to determine when to operate the circulation pump, so there is also potential to tap into the data generated by those sensors to advance water heating science in general. There are many potential advancements that could be developed in parallel with the technology as it becomes more commercialized, including:

- Monitoring and fault detection
- Benchmarking CDHW performance
- Advancements to increase the accuracy of modeling CDHW performance
- Standardization of preventative maintenance tasks
- Further understanding of DHW load profiles, and changes to the profiles over time

These advancements are akin to a building energy management system, but the key difference is a specialization in DHW, as well as the minimal expense and installation time, which would increase the feasibility of widespread usage.

There could be widespread cost-effective energy savings with the full commercialization of this technology. Utility rebate program and incentives are the best way to achieve these goals.

Highlighted Case Studies

The below case studies are selected samples of past research for this measure. They were selected as a diverse sample of the work that has been done to date, both in cold and warm climates and through energy efficiency and emerging technology programs. Additional details can be found in the full reports cited within the Key Resources and References for Additional Information section.

Southern California Gas On-Demand Efficiency Program

The Southern California Gas Company began the third-party On-Demand Efficiency (ODE) program in 2008. For the first two years, they included monitoring equipment at about 12% of the 300 installation sites to review the technology's savings performance results across a range of multi-family buildings. The sites were monitored for four weeks, alternating on a weekly basis between continuous pump operation and demand mode. In total, 35 multi-family sites were monitored. Savings at each site ranged from 498 therms/yr to 2,870 therms/yr (17.8 therms/apt to 95.7 therms/apt).¹ The average pump-level savings were 1,526 therms/yr (34.7 therms/apt). When the average savings are spread across all 300 installation sites, the estimated savings over the first two program years totaled about 458,000 therms. This compared well to the original ex ante estimate of 474,900 therms.

Project	# of apts per loop	Therms/yr Savings	Therms/yr Per Apt
A	50	1107	22.1
B	46	885	19.2
C	39	810	20.8
D	20	1324	66.2
E	24	1043	43.5
F	32	2127	66.5
G	39	943	24.2
H	40	1087	27.2
I	29	2211	76.2
J	39	2579	66.1
K	43	1404	32.7
L	133	1788	13.4
M	189	2321	12.3
N	32	1587	49.6
O	49	1878	38.3
P	49	1878	38.3
Q	39	993	25.5
R	43	1242	28.9
S	50	1960	39.2
T	40	1396	34.9
U	38	1951	51.3
V	36	1544	42.9
W	20	1191	59.6
X	30	631	21.0
Y	30	799	26.6
Z	28	498	17.8
AA	30	1099	36.6
BB	28	1302	46.5
CC	49	1110	22.7
DD	32	2605	81.4
EE	42	1931	46.0
FF	50	907	18.1
GG	30	2870	95.7
HH	23	1942	84.4
II	49	2455	50.1
Total for 35 Sites	1540	53,398	
Average	44	1526	therms
Average Per Apartment		34.7	therms
Controls in PY2008/09 Program		300	
Est'd. PY2008/09 Savings		457,697	therms

Figure 4. Southern California Gas On-Demand Efficiency Program 2008-2009 Monitored Results¹
 Electric savings also varied by site, ranging from 582 kWh/yr to 1,799 kWh/yr.¹ However, this was likely due in part at least to the range of pre-existing pump wattage. The smallest monitored pumps were 85 Watts while the largest were 215 Watts. The average savings was 1,236 kWh/yr (30.1 kWh/apt).¹

The ODE program explored dependent variables that could provide reasonable predictors of savings, including the number of apartments on the recirculation loop, number of building stories, and savings by total storage capacity. The latter dependent variable showed the strongest R-squared with savings and the ODE program did attempt to structure the rebate on total hot water storage capacity for a brief period. However, they found the rebate structure to be less than ideal and reverted to offering a fixed, prescriptive rebate that covers the total installed cost of the controller.

Overall, the ODE program was found to be a reliable and cost-effective energy efficiency measure, showing a realization rate of 96% of their original ex ante estimate of gas savings.¹ The program has continued to grow and installed over 1,200 on-demand controllers in 2013. As a result, Southern California Gas has also increased the level of funding to meet the increasing demand for the program through 2014.

Nicor Gas Emerging Technology Program

The Nicor Gas Emerging Technology Program completed pilot field testing of this measure at two multi-family building sites in 2013. This work included detailed data acquisition and monitoring, in addition to the gathering and review of feedback from the property manager. The monitoring was executed over a period of 18 weeks from December 2012 to April 2013 and the energy savings results were consistent with the results from previously completed field-based testing in California. The field testing also provided important information on installation costs and best practices, assisted in the development of early market contractor support, and provided needed data to validate energy savings and cost-effectiveness within the Chicagoland area. The Nicor Gas ETP selected two vintage walk-up multi-family buildings with CDHW systems and dedicated recirculation return lines.

Table 5. Nicor Gas Field Testing Sites

	Multi-family Building #1	Multi-family Building #2
Units	51 units, 3 stories	23 units, 3 stories
Boiler	(1) Laars Mighty Therm Model PW0500	(1) Laars Mighty Therm Model PW0325
Storage	(2) 119 gallon tanks	(1) 119 gallon tank
Insulated DHW Pipe	Yes	No

Data was collected on the DHW boiler gas valve firing time, the recirculation pump run time, and the DHW flow rate (consumption). The gas valve firing time was multiplied by the boiler nameplate input rating to calculate gas consumption. The recirculation pump run time was used in combination with the pump input rating to calculate electric usage. The water flow measurement used a reed switch that gathered data in 15-minute increments. The Nicor Gas ETP worked with a manufacturer to develop a data acquisition system that could wirelessly transmit the collected data daily to ensure proper functioning of the site and allow for intermittent data gathering and analysis. The on-demand controls were installed with an automatic switching timer for the 18-week monitoring period. The timer switched the CDHW system from on-demand mode to continuous mode on an alternating weekly cycle. A weekly alternating schedule was selected to follow protocols from previous research and allow comparisons to other field studies’ datasets.

The Nicor Gas ETP project results were positive and generally consistent with the results seen in previous studies. Savings percentages were slightly higher than in some of the field results in more mild climates, such as California. The increased savings are due to the lower inlet water temperatures and lower average winter temperatures found in the Chicago area.

Table 6. Nicor Gas Field Testing Results

	Multi-family Building #1	Multi-family Building #2
Yearly gas savings (therms)	2,282	1,449
Yearly gas savings (% of gas used for DHW)	19.9%	22.8%
Yearly gas savings (\$)	\$1,918	\$1,089
Yearly electric savings (kWh)	725	566
Yearly electric savings (\$)	\$55	\$43
Total yearly cost savings (\$)	\$1,973	\$1,132
Therm savings per dwelling unit	44.75	62.99
Simple payback with a \$2,100 installation cost	1.06 years	1.86 years

Source: Bender, Thomas and Kosar, Douglas. Gas Technology Institute. 2013. Nicor Gas Energy Efficiency Emerging Technology Program, 1003: Demand-based Domestic Hot Water Recirculation Public Project Report. Nicor Gas Energy Efficiency Program.

A critical feature of on-demand controls is their ability to meet tenant DHW needs without interruption. The property management company chose to not provide notification of the on-demand control installation to tenants. The management company keeps accurate records of all tenant complaints for follow-up and informed the Nicor Gas ETP that multi-family building #2 had no complaints concerning lack of hot water. Multi-family building #1 had three phone-in complaints due to excessive wait for hot water. Two of these complaints occurred when the pump was in 24/7 operation mode and are thus attributed to other causes rather than the demand controls. Although one complaint did occur during on-demand mode, the Nicor Gas ETP and property management company determined that all three complaints were caused by faulty shower mixing valves. The leaking valves led to bypass of the recirculation line, preventing the system from operating properly.

Savings, cost-effectiveness, and customer feedback were strong for this pilot and Nicor Gas chose to transition this measure into their Multi-Family Comprehensive Energy Efficiency Program in 2013. Additional details can be found at: www.NicorGasRebates.com/multifamily.

DOE ARIES Collaborative in New York

The ARIES (Advanced Residential Integrated Energy Solutions) Collaborative is a Department of Energy (DOE) Building America research team led by The Levy Partnership in New York. ARIES focuses on reducing energy use in both new and existing residential buildings. This research compared multiple control strategies – demand control, timer control, temperature controller, temperature modulation controller – to the baseline 24/7 pump operation case to determine domestic hot water (DHW) system savings potential. The Levy Partnership installed controls at four multi-family sites, ranging from 3 to 16 stories in height with 51 to 150 apartment units. All four sites had natural gas water heating and the control strategies were alternated for 1-2 weeks. The monitoring of this field testing is still on-going as of the time of this writing; however, the results from one of the building sites (site #2) are now available.

ARIES performed a multi-linear regression analysis to compare the site #2 results from each control strategy to the baseline (constant) mode. The control strategy that offered the greatest savings was the combination of demand controls and temperature modulation with an average DHW energy savings of 16.3%, closely followed by the demand controls only with an average

DHW energy savings of 15.1%.¹⁶ Temperature modulation alone averaged 2.2% savings in DHW energy consumption. The installed cost of the demand control system was \$3,000 and the installed cost of the temperature modulation controls was \$2,000. Given the respective prices and average savings for the control strategies, demand controls alone offered the swiftest simple payback for the customer – typically about one year. The simple payback for a combination of demand controls and temperature modulation was about 1.4 years and 7.6 years for temperature modulation only controls.¹⁶

This field study also researched the interactive effects of better DHW pumping control on the space cooling operations at site #2. Since DHW control strategies reduce dissipation of energy from hot water pipes that run through the living spaces of buildings, the cooling load is reduced during the summer months. To determine the impact of these savings, ARIES assumed a 100% offset with a SEER 8 air-conditioning unit and found the cooling interactive effect increased overall energy savings by about 18%.¹⁶ With this additive interactive effect, demand controls paired with temperature modulation could save up to 19.3% of DHW energy, demand controls only could save up to 18.1%, and temperature modulation alone could save up to 2.7%.¹⁶

Previous research has not considered the role of interactive effects on space cooling – or space heating either. However, these limited results from the ARIES Collaborative suggest that the interactive effects noteworthy and should be taken into consideration in future research. Once more robust datasets are available, these additional savings could be considered within utility work papers to provide an incremental increase in prescriptive savings.

Key Resources and References for Additional Information

¹ Benningfield Group. 2009. PY2009 Monitoring Report: Demand Control for Multifamily Central Domestic Hot Water, prepared for Southern California Gas Company.

² California Public Utility Commission. DEER Database for Energy-Efficient Resources. Version 2011 4.01 for Use in the California IOU 2013-14 Energy Efficiency Planning. <http://www.deeresources.com>. EUL/RUL Values (updated 10 October 2008) http://www.deeresources.com/files/deer0911planning/downloads/EUL_Summary_10-1-08.xls Accessed December 23, 2013.

³ Zhang, Yanda. Heschong Mahone Group. 2013. Multifamily Central Domestic Hot Water Distribution Systems. California Energy Commission. Publication Number: CEC-500-2013-011

⁴ California Utilities Statewide Codes and Standards Team, Multifamily Central DHW and Solar Water Heating, Codes and Standards Enhancement Initiative (CASE) for 2013 California Building Energy Efficiency Standards. October 2011.

⁵ International Code Council. International Codes-Adoption by State (October 2013). <http://www.iccsafe.org/gr/Documents/stateadoptions.pdf>. Accessed December 27, 2013.

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- ⁸ Bender, Thomas and Kosar, Douglas. Gas Technology Institute. 2013. Nicor Gas Energy Efficiency Emerging Technology Program, 1003: Demand-based Domestic Hot Water Recirculation Public Project Report. Nicor Gas Energy Efficiency Program.
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- ¹² Illinois Stakeholder Advisory Group. Net-to-Gross Framework documentation for utility-specific NTG values. <http://www.ilsag.info/net-to-gross-framework.html>. Accessed December 18, 2013.
- ¹³ MassSave. October 2012. Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures. 2013-2015 Program Years – Plan Version.
- ¹⁴ California Public Utilities Commission, Energy Division. Workpaper Disposition for On-Demand Pump Control for Central Domestic Hot Water Systems. February 28, 2013.
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- ¹⁶ ARIES Collaborative, The Levy Partnership. Dentz, Jordan. Control Strategies to Reduce Energy Consumption of Central Domestic Hot Water Systems. Presentation at NYSERDA Building Power 2013 MPP Partner Summit. October 28, 2013. Tarrytown, NY.